

COLOUR MONITORING

The invention relates to colour monitoring.

5 PCT application WO 96/05489 describes a colour inspection system and method by which a video camera is controlled for the acquisition of a colour image under varying image capture conditions. A fast moving (approximately 500 metres min⁻¹) web of printed material
10 passing in front of the camera is monitored. The video camera of such a system has a red, green and blue output and is provided with a controllable iris aperture, a controllable overall RGB signal gain, independently controllable RGB signal channel gain, or a controllable RGB
15 signal channel balance. The controllable parameters are controlled by a control unit in the form of a personal computer or other suitable processor having an image capture board. The processor generates signals from an image signal received from the video camera, the signals
20 being used to correct the controllable parameters to improve camera image capture performance.

The subject of the present application comprises an improvement to the system and methods described in the
25 aforementioned PCT application.

A first problem of the prior system and colour monitoring systems in general to be addressed by embodiments of the present invention relates to the
30 correction of camera output when used to monitor colours. In an ideal world, the video camera characteristic in terms of RGB output would be a linear characteristic so that zero light intensity from a completely black scene would give

zero voltage outputs from a camera. Again, in an ideal world, the RGB outputs would increase linearly accordingly to increasing light intensity for a particular given colour. Unfortunately, real cameras exhibit an imperfect
5 characteristic dependent upon ambient temperature giving an offset from the origin (i.e. a non-zero volt output for zero light intensity input), after which there follows a generally linear response region which then, above a particular light intensity will tend to flatten out to give
10 a non-linear response.

A second problem of the prior system to be addressed by embodiments of the present invention concerns the effects of non-uniformity of lighting characteristics across a
15 material to be monitored. Again, in an ideal world, an unprinted stationary (or moving) material of uniform colour and consistency when monitored by a video camera would appear as such. However, where colour monitoring is to be carried out, non-uniform lighting can cause the camera
20 monitor to perceive different parts of the camera field of view (which typically may be of an A4-sized area) to have a different colour or different lightness value. Ambient lighting by its nature is non-uniform both spatially and temporally and is therefore inappropriate for colour
25 monitoring. A pure flash lighting of the web during colour monitoring procedures is generally used but even this has problems due to reflections within the lighting (monitoring) enclosure and flash to flash intensity variations. Also, the physical characteristics of the
30 monitored material itself and the variation in angle of lighting on the material across the field of view means that different parts will reflect or transmit incident light to different extents, and this is further dependent

on where the lighting source is positioned. In other words, the material will not only reflect incident light but also transmit it to a degree and, since it is reflected light which a camera with a front-mounted lighting source actually monitors (which will include reflections from the monitoring enclosure itself subsequently passing again through the translucent material), a uniform coloured piece of material may be interpreted by a camera as being of non-uniform colour/ lightness because of the type and angle of the light sources, positioning of the camera, type of enclosure and composition of the material itself.

A third problem which has been encountered in colour monitoring is that the print design sometimes contains areas of "half-tone" and "vignettes" - i.e. areas of non-uniform colour, which nevertheless need to be checked for consistency through the print run, and in subsequent runs. To do this, the same area in the repeat must be inspected with high spatial accuracy. In prior systems, triggering of image capture and lighting is typically done by registration marks located, for instance, at regular intervals and to one side of the web. When a registration mark is detected by a sensor, both the illuminating flash is triggered and image capture carried out in a synchronized fashion. This type of triggering is advantageous in normal situations in that even if the speed of the web is inconsistent, triggering based upon web positions will always result in a consistent image capture of a particular part of the web. In this context, it must be appreciated that in most situations, the printed web is likely to be a complex mix of colours which need to be accurately monitored, but which also have a given repeat length. By carrying out the aforementioned type of

triggering with registration marks appropriately positioned with respect to the cameras field of view and the repeat length, it can be ensured that the colour monitoring is always done consistently with regard to the web repeat.

5 However, using registration marks in the conventional manner, the high spatial accuracy required for consistent checking of specific areas is not achievable. Neither can this conventional type of system cope with print webs which do not have a consistent and predictable repeat length.

10 Also, in high speed web operation, it is not uncommon for the web to shift sideways by a few centimetres between repeats and this also causes problems with the conventional image capture method.

15 With a view to solving or reducing the first problem mentioned above, there is provided a method of calibrating a colour monitoring system so as to compensate for non-ideal real camera characteristics, the method comprising: establishing a camera offset by measuring or calculating
20 the output voltage of the camera when substantially no light falls on any of its sensor elements, hereinafter referred to as establishing the offset; establishing the point at which a graph of input light intensity against camera output voltage starts to deviate from a
25 substantially linear characteristic, hereinafter referred to as establishing the knee; and restricting the amount of light incident on all sensor elements of the camera such that the maximum output corresponds to a voltage at, or below, the knee, and lower light intensities are all within
30 the range of linear operation.

The step of establishing of camera offset may be carried out on a periodical basis to keep pace with the

variations in offset value caused by variation in ambient conditions.

The step of establishing offset may be carried out
5 whenever an image capture operation for capturing a desired image to be monitored is to be carried out.

Setting the point of zero light intensity may be achieved by closing the camera iris.

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Setting the point of zero light intensity may be achieved by setting the camera to monitor a black image, or a black part of an image field of the camera.

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Setting the point of zero light intensity may be achieved by extrapolating from measurements obtained from two or more points of known reflectance somewhere in an image field of the camera.

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Preferably, one point of known reflectance comprises an integral part of the desired image itself.

Preferably, one point of known reflectance comprises a white reference tile within the image field.

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This has the advantage that it may be done for every image captured.

Preferably, there is provided a source of maximum light
30 reflectance within the image field by ensuring that a white object is present somewhere in the image field.

Restricting the camera to operate within the linear region may be achieved by reducing the camera aperture by closing the iris to a predetermined degree such that the output voltage when measuring the source of maximum light intensity corresponds to a camera output voltage at or below the knee.

In practice, it is found with preferred embodiments that for a typical camera, the iris may be restricted so as to give a proportionate reduction in the full scale output voltage of the camera so as to ensure that a perfect white reflector registers at the top of the linear region and to then scale down to find appropriate values of camera output versus light intensity.

Preferably, the step of establishing the knee is carried out less frequently than the step of establishing the offset and may be carried out before commencing and/or after completing a plurality of print runs each comprising a plurality of image capture operations.

With a view to solving or reducing the second problem mentioned above, there is provided a method of compensating for non-uniformity of lighting across a camera field of view when performing an image capture operation to be monitored by the camera, the method comprising:

positioning substantially uncoloured or uniformly surface coloured material of known colour characteristics in a field of view of the camera; and

capturing image data from the camera and storing such captured image data as a "uniformity image" in memory the

image data of the uniformity image including information concerning the degree of light reflected from the different spatial areas of the material detected by the camera.

5 By utilizing image data from the camera relating to the known coloured material, differences in data from the different parts of the field of camera view are attributable to the non-uniformity of lighting. Using this position related data, subsequently captured image data can
10 be adjusted to be corrected for this positional effect.

In accordance with the method, image capture operations of images to be inspected are thereafter carried out and compensation for non-uniform lighting conditions effected
15 for each captured image. The compensation may comprise normalising each newly captured image across the camera field of view by determining spatial adjustment factors from the uniformity image and, where no uniformity image data is available for a particular spatial location,
20 interpolating between the various positions or extrapolating beyond them.

The step of normalising image data may comprise the sub-steps of: recording output data from the camera
25 averaged over all the pixels in a given spatial area of the sample with the sample at a first, training, position on the printed web to give first position camera channel output data C_T ; and recording the camera output data from the camera averaged over all the pixels in the same given
30 spatial area of the sample with the sample at a second position on the printed web having different lighting conditions to give second position camera channel output data C_S .

The step of normalizing may comprise normalizing the second position camera channel output data C_s prior to comparing them to the trained values from the first position camera channel output data C_T by processing them in accordance with the following equation: $C_s \times C_1/C_2$, where C_1 is the average channel value for the area of the unprinted web corresponding to the first position, and C_2 is the average channel value for the unprinted web corresponding to the second, differently lighted position.

Preferably, three camera channels R, G and B (red, green, blue) are present such that, for instance, for the red channel R, the first position camera channel output data is R_T , the second position camera channel output data is R_s , the average red value for the area of the unprinted web corresponding to the starting position is R_1 and the average value of the unprinted web corresponding to the second, differently lighted, position is R_2 .

It will be appreciated in the above that the geometry of the illumination source and the camera are arranged so as to avoid specular reflections in both the "uniformity image" and the printed web image.

Operation must be made in the linear region of the camera channel and using the correct current offset.

Both the method of the first and second aspect, would in practice, be carried out for each of the individual camera channels (for instance, red (R), green (G) and blue (B)).

With a view to solving or reducing the third problem mentioned above, there is provided a method for the capture and analysis of image data of a moving material monitored by a camera having its field of view trained on the material, the method comprising:

storing a pattern recognition model comprising image data corresponding to at least part of a pattern repeat printed on the monitored material;

measuring the displacement of the pattern model in each captured image of the printed web relative to a captured training image to sub-pixel accuracy; and

calculating the colour of the displaced vignette or half-tone area allowing for sub-pixel displacements (both vertical and horizontal).

Subsequent to the step of measuring the displacement and prior to the step of calculating the colour, there may be performed the following steps:

on the basis of the measured displacement, calculating a displacement value by which a camera used to capture images of the web is to be moved in a transverse direction relative to the web so as to substantially reduce transverse displacement of the pattern recognition model relative to the captured training image during a subsequent image capture operation;

moving said camera accordingly to the calculated displacement value; and

carrying out said subsequent image capture operation.

Preferably, following said step of carrying out said subsequent image capture operation, there is then carried
5 out a further step comprising measuring the displacement of the pattern model in the newly captured image of the printed web to sub-pixel accuracy.

Preferably, displacements of the pattern model in the
10 longitudinal direction of the web are compensated for by delaying or speeding up a trigger signal fed to the camera, so as to perform an image capture operation relatively earlier or later according to a measured longitudinal displacement of the pattern recognition model relative to
15 the captured training image.

The method may further include the steps of:

monitoring synchronization signals (SYNC) from the
20 camera; and

in accordance with the operating characteristics of the camera, triggering a lighting source during the camera vertical blanking interval so as to illuminate the material
25 during image capture periods.

As will be appreciated from the above, capture of image data according to this aspect of the invention is based upon recognising the presence and position of the
30 particular pattern model in a captured image during subsequent image processing rather than by triggering image capture upon the web achieving a particular position. The method may therefore be regarded as, and will be referred

to as, an "opportunistic triggering" technique. In this way, the sub-pixel inspection method also facilitates the use of a normal video camera as opposed to a specialist (triggered) camera system. Image capture may take place at
5 time intervals which can be externally monitored by looking at the camera SYNC signals and illumination of the web at the appropriate moments can be triggered by the SYNC signals. An advantage in performing image capture in this way, is that an ordinary video camera, as opposed to a
10 higher cost image capture system, may be utilised. However, it will be appreciated that a triggerable camera may still be used with this method.

Preferably, image data from the camera is analyzed so
15 as to carry out a pattern recognition operation based upon the pattern recognition model to determine the physical position of the printed pattern repeat on the web in the field of view of the camera at the time of image capture.

20 Following successful pattern recognition, analysis of the image captured to inspect the required areas displaced by the same displacements as the pattern model may be carried out with sub-pixel accuracy.

25 Preferably, the opportunistic triggering technique is utilised in conjunction with the lighting non-uniformity compensating method which is also to be carried out to sub-pixel accuracy.

30 Specific embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows in schematic form a colour monitoring apparatus;

Figure 2 is a schematic graph showing camera output in
5 volts, against input light intensity;

Figure 3 is a schematic diagram showing a graduated grey scale which may be incorporated within an image to be captured for ascertaining camera response;

10 Figure 4 shows a black tile and a white tile forming part of a test image;

Figure 5 illustrates how readings corresponding to the
15 black tile and white tile of Figure 4 may be used to determine a camera offset;

Figure 6 is a schematic diagram showing possible relative size of repeat length with respect to size of
20 field of view;

Figures 7A to 7C show respectively first to third patterns to be printed by first to third cylinders and to be monitored using an opportunistic triggering technique;

25 Figures 8 and 9 show respectively a training image and a newly captured image;

Figures 10A and 10B show a perimeter area of a
30 displaced image which it is desired to inspect to sub-pixel accuracy; and

Figure 11 shows a hardware arrangement featuring a scanner arranged to move a camera and flash in a transverse direction relative to a moving web.

5 Referring to Figure 1 of the accompanying drawings, there is shown a typical set of apparatus which may be used for colour monitoring. The apparatus comprises an interface unit for interfacing to a conventional commercially available video camera 1, having a red, green,
10 blue output (RGB output) and having a controllable iris aperture, a controllable overall gain, independently controllable RGB signal channel gains, or a controllable signal channel balance. The interface comprises an RS232C bus 2 to enable remote control of the camera and a
15 conventional commercially available personal computer 3 having a conventional commercially available image capture board 4. The camera 1 is positioned within a lighting box 5 which also contains a flash lighting source 6. A trigger circuit 7 is provided which is connected to the camera
20 output 1, to the lighting source 6 and to the image capture board 4 and to the PC 3. A monitor 8 is also provided.

The computer is adapted for control of the camera via the RS232C data bus, by means of a dedicated application
25 programme. The dedicated application programme may form part of a larger computer programme, or may be run in conjunction with other application programmes.

Aspects of the present invention are primarily directed
30 towards improving the usability of such a system by addressing the problems of non-linearity of camera characteristic, non-uniformity of lighting of a specimen to

be monitored and accurately measuring the colour of non-uniform areas on the web.

Concerning the first problem of non-linearity of camera characteristics, an embodiment of the first aspect of the present invention will now be described with reference to Figures 2 to 5.

Figure 2 shows a typical camera characteristic in terms of increasing light intensity of a known colour (R, G or B) along the horizontal axis and measured R, G or B output in volts along the vertical axis.

The graph of Figure 2 may be obtained, for instance, by capturing the image of a collection of paint chips of graduated colour, such as the grey scale 30 shown in Figure 3. All paint chips must be captured in a single image capture period and under uniform illumination.

The known colours can be measured using established colorimetric techniques, i.e. a colorimeter or spectrophotometer traceable to national colour measurement standards, coupled with a standard conversion matrix to convert the CIE tristimulus measurements into camera R, G, B values.

Referring to Figure 3, the left most paint chip 31 is black, the right most paint chip 32 is white and, in between, are chips of intermediate shades of grey. The images of each of those chips are captured to plot the graph of Figure 2. Note that the vertical axis may be any one of the measured R, G or B outputs and also that in obtaining this graph the iris of the camera 1 is set so

that the white chip produces a near saturation R, G and B output, the horizontal axis represents increasing light intensity from black to white, in known increments as determined by the test pattern of Figure 3.

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Referring to the characteristic plot of Figure 2, it can be seen that the graph is generally linear, but tends to flatten out above a knee point (K). Also, there is an origin offset (OFF). It will be seen that in the plot illustrated, the paint chip 32 representing the highest light intensity level, pure white (i.e. the most white) is shown as a plotted point 20 which falls within the non-linear region. The graph of Figure 2 also shows the next "nearest to white" paint chip as giving a plotted point 21 which is in the non-linear region.

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In an ideal world, the camera characteristic would pass through the origin and be totally linear. However, as seen from the above, conventional video cameras do not operate in this ideal fashion and it is necessary to compensate for this non-linearity if accurate determinations of light intensity are to be made.

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In order to provide an effective compensation, the offset (OFF) and the knee point (K) need to be determined.

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To complicate matters more, camera characteristics including the offset change by measurable amounts as the camera 1 warms up and cools down, and as ambient temperature changes. So for accurate colour monitoring purposes, compensation needs to occur by varying amounts every time an image is captured.

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In order to determine the offset, a black object (zero reflectance) may be included in the image at each image capture point. By analyzing the output data from the camera relating to the black object area of the image, the average corresponding R, G and B output values may be found and those values can be directly taken as the offset values for the respective R, G and B channels.

The drawback with this approach is that it is difficult to get a perfectly black object, and to make sure that it picks up no contaminant prior to being monitored that changes its colour. In view of this, a better approach is to use a white ceramic tile 40 (see Figure 4) of known RGB, and a black ceramic tile 41 of known RGB simultaneously present within the camera field of view 42 (the RGBs can be measured using a colorimeter or a spectrophotometer traceable to national colour measurement standards and by using a standard matrix for converting those measurements to camera RGB values). Ceramic tiles may be easily cleaned by using lens tissue before image capture takes place.

Prior to using this black and white tile method, it must be established that the camera is operating in a linear fashion. This may be done by forming the graph of Figure 2, restricting the size of aperture to avoid going beyond the knee, and then repeating the graph measurements to check that all of the points on the measured grey scale now produce R, G, B outputs within the linear region. All of the grey scale needs to be captured during a single capture period (i.e. from a single image) under uniform lighting conditions. Adjusting the voltage output to be a proportionate reduction of its full scale value when inspecting white portions of the image will in practice,

suffice in many practical situations as long as the whole field of view is uniformly lit or the white tile is in a sufficiently well lit part of the field of view that no part of the field of view produces above knee signals and
5 may be used for all camera operations once it has been verified that the camera is indeed operating wholly within the linear zone.

Having ensured that the camera is being operated below
10 its knee point, a graph as shown in Figure 5 may be obtained from the measured white tile and black tile by drawing a line between the two known points and extending that line to find the offset from the origin.

15 The two known points can be measured using established colorimetric techniques, i.e. a colorimeter or spectrophotometer traceable to national colour measurement standards and by using a standard conversion matrix for converting these measurements to camera R, G, B values.

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If it is ensured that the black and white tiles are permanently in the field of view, then the calculation of offset (by using the two points given by black and white tiles) may be done by the computer each time an image is
25 monitored to provide reliable compensation for camera characteristics in real time situations.

An alternative for checking the offset is to close the iris of the camera and use the R, G and B average values
30 with the iris closed, to directly determine the offset.

Turning now to the second problem of prior art systems which relate to non-uniformity of lighting characteristics

across the material to be monitored, preferred embodiments of methods for compensating such non-uniformity will now be described.

5 Non-uniformities in lighting, particular characteristics (e.g. internal reflections) of the lighting enclosure from which individual images are captured, and physical characteristics of the substrate material can all cause anomalies in the amount of reflected light (or
10 transmitted light in the case of a back-lit web) arriving at the camera lens from different spatial locations within the camera field of view and need to be compensated for.

The principle behind such a compensation technique is
15 to capture an image of a uniformly coloured or unprinted sample of material. Spatial image data from the unprinted web and incident to the camera lens embodies data concerning not only the uniformity of incident rays in different parts of the field of view but also the
20 translucency of the web and the internal reflections from the lighting enclosure.

It is known, of course, that the unprinted sample of material is, in fact, an essentially uniform surface. By
25 detecting spatial non-uniformities in camera output over the field of view, normalising settings may be achieved, so that individual output data from individual spatial areas is compensated. For example, the average R, G and B of an area of surface colour are recorded at its starting
30 (trained) position, R_T , G_T , B_T . When the image is next captured, suppose this area in the design has moved to a less well-lit position and its average R, G and B are now R_S , G_S , B_S . If R_i , G_i , B_i , are the average RGB values for the

area of the unprinted web corresponding to the starting position, and R_2 , G_2 , B_2 the average values of the unprinted web corresponding to the less well-lit position, then R_s , G_s , B_s are normalized as follows before comparing them with
5 the trained values R_T , G_T , B_T :

$R_s \times R_1/R_2$, and the same for G_s and B_s .

Concerning the third aspect, there will now be
10 described how an opportunist triggering technique may be used to monitor a moving web of material without the need for complex triggering methods.

Referring now to Figure 6, there is shown a typical web
15 of material which it may be desired to monitor. Figure 6 shows schematically, the nominal field of view seen by the monitoring camera and represented by rectangle 60 superimposed over a schematic view of moving web of material 61.

20 It will be appreciated that a pattern printed on the web 61 will have a given repeat length R . The repeat length defines the pattern printed on the web in its entirety and may be wider (as shown here) or narrower than
25 a width W of the field of view 60 of the monitoring camera.

In previous systems, if it was desired to monitor a full repeat of the web 61, or indeed to simply monitor known portions of the sampled web, a reference mark on the
30 web could be used in conjunction with a sensor to trigger an image capture cycle when the web has reached a particular point. In such systems, image capture is driven by the positioning of the web, and the image capture system

must be ready to fire whenever the reference mark aligns with the triggering sensor. To implement such systems, the monitoring camera needs to be of a relatively sophisticated nature.

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Embodiments of the present invention tackle the problem of triggering in a different fashion.

10 In embodiments of the present invention, a basic video camera may be used and image capturing driven by synchronisation (SYNC) signals from the camera itself.

15 According to the method, a particular unique feature within the full repeat (R) has its image data pre-stored in memory, so that it may be used for pattern recognition purposes. With the web of material running, synchronisation signals output from the video camera are monitored and lighting and image capture from the web triggered in accordance with the synchronisation signals, 20 so that whenever the camera itself is ready to perform an image capture operation, and such an image capture operation is called for, lighting of the web is automatically synchronised and carried out on the basis of the SYNC signals.

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Once an image capture operation has been performed, it is necessary to determine what the image is of. In that regard, the captured image data is analyzed using a pattern recognition programme, so as to determine exactly what the 30 image is of, in relation to the unique feature in the pattern repeat. Thereafter, once the system knows exactly what the captured image data is of, standard colour monitoring procedures may be carried out to monitor quality

of printing etc. and utilising any other software compensation techniques with regard to non-linearity compensation/non-uniformity of lighting compensation etc. to determine meaningful results.

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A typical mode of operation of the apparatus of the present invention will now be described.

10 With unprinted web material present and with the aperture restricted (if required) to ensure operation in the linear range of the camera characteristic, an image is captured in order to perform the lighting uniformity compensation referred to earlier. This image is hereinafter referred to as a "uniformity image"

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Thereafter, with the approved printed material running on the press and with white and black reference tiles present, an image is captured. The reference tiles serve to enable an accurate determination of slope and offset of the camera characteristic during each capture operation as described previously and the white tile also serves to control the camera and keep the colour measurements repeatable as described in PCT application WO96/05489. Rectangles may be drawn over particular areas of the pattern to be monitored. A sufficient number of images are captured, in order to record details of the full repeat.

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Next, a training operation is carried out. Training does the following: it automatically selects a pattern model and trains the colours, using lighting uniformity compensation and any other required software adjustments. The system may then be set to what is known as an "auto-inspect" mode, in which it will monitor the colours of the

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areas defined by the rectangles in the training image at ten second intervals throughout the run, giving real-time and logged results. Auto-inspect does the following: captures an image at intervals from the moving web, keeping
5 the camera controlled; finds the pattern model and calculates image displacement from a trained image; inspects the coloured areas, allowing for the displacement and lighting uniformity; logs the results to file; and signals if the colour of any area is beyond warning limits.

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During such automatic inspection, the training image will be displayed at all times and the ongoing measurements of any defined area may be displayed at will.

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This opportunist triggering technique produces a distinct advantage over traditional web-triggering in applications where the print cylinders are not in register with each other.

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For example, in the printing of filter-tip cigarette paper where it is desired to print a cork design on the paper in a seemingly random fashion there is illustrated in Figures 7A to 7C a pattern to be printed by means of three cylinders.

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The first cylinder shown in Figure 7A is utilised to print a manufactures mark 70 (LOGO). The mark (LOGO) needs to be printed once per cigarette.

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The second cylinder shown in Figure 7B is used to print a first colour 71, for example a solid yellow 11. The third cylinder shown in Figure 7C is utilised to print a further pattern 72, for instance a brown colour with gaps

formed in it to allow the yellow to show through those gaps. Prints 71 and 72 together form the cork design.

5 The mark 70 must be printed on every cigarette, but the filter tip design, made up of the first colour 71 from cylinder 2 overlaid by brown from cylinder 3, must appear random, so its repeat is say 3.5 cigarettes.

10 Each cylinder further prints a rectangular box 73-75 at the edge of the web showing its ink colour once per cylinder circumference as well as a text string 76, 77, 78.

15 Because it is desired to produce a non-regular pattern there is no requirement for the cylinders to have the same circumference, nor for them to rotate in phase with each other. The ink boxes therefore appear at random relative to each other, and this causes problems in web-triggered inspection systems.

20 Because it is the colour of the ink boxes which is to be monitored, and because each ink box is a fixed distance from its associated text string, the problem with regard to web-triggering which was encountered in the prior art may be removed altogether by the use of the opportunistic
25 triggering techniques described previously. This is achieved by using the unique text string 76-78 which accompanies each ink box 73-75 as a pattern model, and searching can be done every captured image for all 3 text strings, to thus find the ink boxes 73-75 and then inspect
30 their colour.

Referring now to Figures 8 and 9, there is illustrated a method for inspection of an area of a web of material to sub-pixel accuracy.

5 Figure 8 shows a camera field of view with a web of material 80, on which there is printed a logo 81 and other image data 82 including an inspection area 83. The view shown in Figure 8 is, for instance, an original training image used during setup.

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Figure 9 is an image captured during a subsequent image capture cycle and featuring the same elements as the image shown in Figure 8. In Figure 9, it will be noted that the web has been displaced to the right of the field of view by an amount and that the actual positioning of the design is vertically displaced. This vertical displacement can occur due to triggering inaccuracy or may occur as a result of the use of an opportunistic type triggering method as previously described.

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The element 81 referred to above as the pattern model whose data is stored from the original training image is used as a search pattern to locate the same pattern in the captured image. Once that design has been located in that captured image, its displacement can be calculated which, for instance, may be 50.6 pixels to the right and 73.3 pixels down. Knowing the displacement of the pattern model, the area to be inspected 83 can also be located by using the same displacement, i.e., it will be known that that area is also 50.6 and 73.3 pixels displaced relative to its original position.

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In the newly captured image, a rectangle of pixels may be processed which is slightly larger in area than the original inspection rectangle in the training image and a margin of error given by adding an extra row and an extra column of pixels. Because the displacement involves pixel fractions, the area of the design to be inspected now straddles pixels. Here, the assumption is made that the digitised value of the voltage level corresponding to 0.1 pixel corresponds to 0.1 of the digitized value of the voltage level for that entire pixel. In order to measure the average R, G or B values of the area, a fraction of the pixel values around the perimeter is taken as follows:

Top left corner take $0.4 \times 0.7 \times R, G \text{ or } B$ value of this pixel
Top right corner take $0.6 \times 0.7 \times R, G \text{ or } B$ value of this pixel
Bottom left corner take $0.4 \times 0.3 \times R, G \text{ or } B$ value of this pixel
Bottom right corner take $0.6 \times 0.3 \times R, G \text{ or } B$ value of this pixel
Top row of pixels take $0.7 \times R, G \text{ or } B$ of all these pixels
Bottom row of pixels take $0.3 \times R, G \text{ or } B$ of all these pixels
Left row of pixels take $0.4 \times R, G \text{ or } B$ of all these pixels
Right row of pixels take $0.6 \times R, G \text{ or } B$ of all these pixels

15 Add the R, G or B of each pixel in the displaced area, and the R, G or B of each straddling pixel, weighted as shown in the above table. Divide the grand total by (width \times height), and this gives the average R, G or B of the inspected area to sub-pixel accuracy. Each of the channels
20 R, G and B must be processed independently.

To explain the above further, Figures 10A and 10B are referred to.

Figure 10A shows a training image together with a
5 inspection area 83 to be inspected and marked with a
rectangle A (shown as ----). Each illustrated "square"
represents a pixel and the inspection area necessarily
encompasses whole (integer) pixels. Note that an
unrealistically small inspection area of 5x5 pixels is
10 shown here so as to enable pixel fractions to be
demonstrated. Actual inspection areas used would in
practice be very much larger in area.

Figure 10B shows a captured image with the inspection
15 area 85 displaced by 50.6 pixels in the horizontal (x)
direction and 73.3 pixels in the vertical (y) direction.

For the purposes of the following discussion, it is of
course evident that to illustrate the boundary conditions,
an actual displacement of 50 x 73 cannot be shown in Figure
20 10B. Rather, Figure 10B is used solely for the purposes of
discussing what happens at the subpixel level. The square
A containing inspection area 83 of Figure 10A is shown in
Figure 10B as having moved to position A'. The "floor"
integer pixel position, i.e. the pattern model shifted by
25 50 pixels horizontally and 73 pixels vertically is marked
as rectangle C (shown _._._.).

In the Figure, Δx = fractional pixel horizontal
displacement (+VE meaning displacement to the right); Δy =
30 fractional pixel vertical displacement (+VE means
displacement in a downward direction); x-displ = integer
part of horizontal displacement; y-displ = integer part of
vertical displacement.

In the example given, $\Delta x = 0.6$, $\Delta y = 0.3$, floor x-displ = 50, floor y-displ = 73.

5 If Δx and Δy are positive, a column of pixels to the right of the displaced area and a row of pixels below the displaced area are processed. If Δx and Δy are, on the other hand, negative, a column to the left and a row above are processed.

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The same equations for calculating the fraction of each pixel in the bottom, top, left and right rows and columns in the extended processing area are used whether Δx and/or Δy happen to be positive or negative (+VE or -VE). In otherwords, concerning the perimeter area for the example shown in Figures 8/9 and the displacements of which are illustrated schematically in Figures 10A and 10B, the fractional pixel values providing the weighting as given in the table 1 are shown as shaded areas in Figure 10B and are
 15 obtained by performing the following calculations:

- (i) Top left hand corner pixel = $(1-\Delta y) (1-\Delta x) \times$
R, G or B pixel value
- (ii) Top right hand corner area pixel = $(1-\Delta y)$
 25 $(\Delta x) \times$ R, G or B pixel value
- (iii) Bottom left corner pixel = $(\Delta y) (1-\Delta x) \times$ R, G or
B pixel value
- (iv) Bottom right corner pixel = $(\Delta y) (\Delta x) \times$ R, G
or B pixel value
- 30 (v) Top row of pixels = $(1-\Delta y) \times$ R, G or B pixel
value
- (vi) Bottom row of pixels = $\Delta y \times$ R, G or B pixel
value

(vii) Left row of pixels = $(1-\Delta x) \times R, G \text{ or } B \text{ pixel value}$

(viii) Right row of pixels = $\Delta x \times R, G \text{ or } B \text{ pixel value}$

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Again, when inspecting these perimeter values the assumption is made that the digitized value of the voltage level corresponding to 0.1 pixel corresponds to 0.1 of the digitized value of the voltage level for that entire pixel.

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By referring to the above, it may be seen that there is provided a method for inspection of an area of a web of material to sub-pixel accuracy which facilitates web inspection even when parts of the design on the entire web appear to vary in a seemingly random fashion.

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Figure 11 shows a hardware arrangement with a camera 85 and flash 86 associated with one another on a moving sled 87 of a scanner 88. The camera 85, flash 86 and sled 87 of the scanner 88 are shown mounted underneath a moving web of material 89. A lighting enclosure 90 is also associated with the scanner 88. In the arrangement shown, the web is arranged to move from left to right as shown in the figure and the camera and flash are mounted for up and down movement.

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In operation, the camera and flash move transversely with respect to the web so as to provide a means of mechanical compensation for transverse ("x"-axis) movement of the web. The amount of mechanical movement of the camera and flash is calculated by means of the above-mentioned procedure for measuring the displacement of a pre-stored pattern model in a captured image relative to

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its position in a training image and translating (e.g. using a scaling factor) that displacement value into a "real-world" value by which the camera is moved so as to mechanically compensate by reducing said displacement.

5 After movement of the camera 85 and flash 86, there is then performed a subsequent image capture operation in which the transverse movement of the web is already compensated to a degree.

10 Such mechanical compensation is not as accurate as that which may be achievable by sub-pixel interpolation as previously described, so in practice a combination of the mechanical method together with sub-pixel interpolation is preferred. In this combination method, following movement
15 of camera 85/flash 86, pattern model displacement is again measured and the step of colour calculating then performed.

When the camera 85 is a triggered camera, a variable delay can be introduced between the sensing of the trigger
20 signal (the trigger signal being activated from a feature in the design repeat) and the initiation of the flash and image capture. This allows the "y" displacement to be compensated. Once again, this method is not as accurate as the sub-pixel interpolation method, so, ideally, those
25 methods are used in combination.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and
30 which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except
5 combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be
10 replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

15 The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying
20 claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.